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ABSTRACT

A study evaluated the feasibility of introducing unheated outside air into the airstream of a cross-flow welding exhaust system to reduce heating energy costs of a school welding laboratory. The physical facility used was the agricultural mechanics laboratory at the University of Arizona, which is similar to facilities in which instruction in agricultural mechanics is conducted in Arizona high schools offering vocational agriculture. An air change system was incorporated into the existing welding fume exhaust system and evaluated on its ability to conserve heat energy, to complement and enhance the efficiency of the cross-flow system, and to capture and exhaust welding fumes. Data analyses revealed that heat loss from the welding laboratory was reduced approximately 48 percent. The air charge system complemented the cross-flow exhaust system by increasing the capture velocity of airflow toward the intake boot of the system at the surface of the welding table. When maximum air charge was used, the amount of iron oxide breathed by the student welder was reduced by 23 percent compared to the amount inhaled when welding fumes were exhausted only by the cross-flow ventilating system. (YLB)

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An Evaluation of a Welding Fumes Exhaust System

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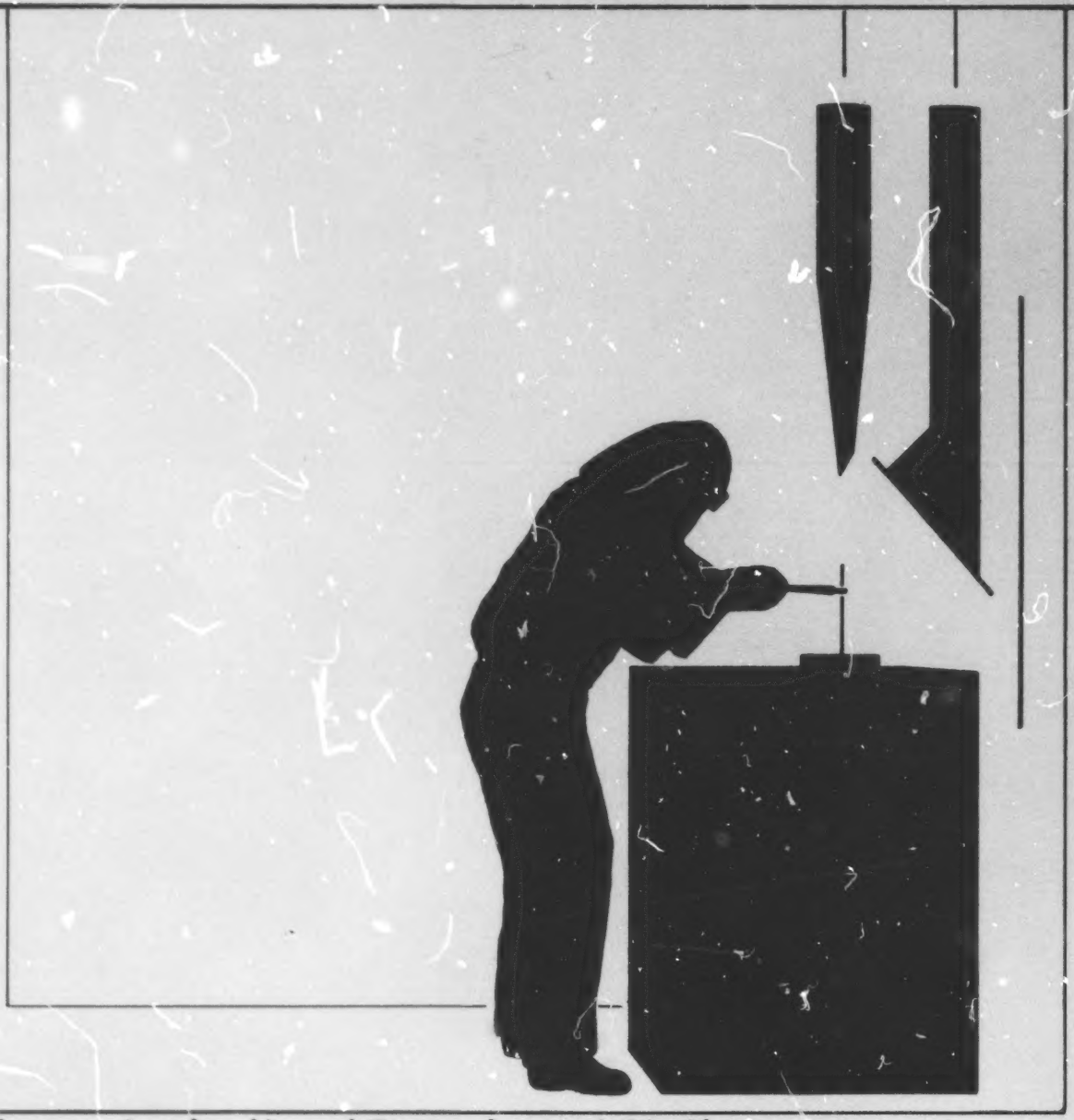

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AN EVALUATION OF A WELDING FUMES EXHAUST SYSTEM

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October, 1983
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AN EVALUATION OF A WELDING FUMES EXHAUST SYSTEM

INTRODUCTION

Electric and gas welding operations produce fumes which are recognized as hazardous to human health. Welding fumes consist of gases and particulates which when absorbed by the body for a period of time are considered capable of producing chronic health problems. The immediate effects which are most obvious to persons in an environment of welding fumes are the discomfort and concern resulting from irritation to eyes, skin and mucous membranes of the respiratory system.

The development of occupational skills in welding is a common part of vocational programs in public secondary and postsecondary schools nationally. Nearly all schools utilize mechanical methods of removing fumes from the welding laboratory. The most common evacuation system used is to collect the fumes and exhaust them to the atmosphere by ventilating fans. When properly installed, the system is effective, relatively low cost and virtually maintenance free compared to other methods. Unfortunately, the exhausted air results in a loss of heat as outside air is brought in to replace that evacuated. The amount of heat loss can be determined by knowing the difference in room and outside air temperature and the volume of air exhausted. To meet the standards established by the Occupational Safety and Health Administration (OSHA), United States Department of Labor, (1977: 62845A-62846) "a minimum airflow rate of 2,000 cubic feet per welder shall be provided." Where pick-up hoods are placed as near as possible to the work area, OSHA standards for the airflow rate "shall be sufficient to maintain a velocity of 100 lineal feet per minute in the direction of the hood." To achieve this velocity, an airflow of nearly 600 cubic feet per minute at the point of welding is required. To meet either standard, the amount of air moved in the typical school welding laboratory could conceivably result in a sizable energy cost to reheat outside air for student and instructor comfort.

Statement of the Problem

The problem under investigation was to evaluate the feasibility of introducing unheated outside air into the airstream of a cross-flow welding exhaust system to reduce heating energy costs of a school welding laboratory.

Purpose of Study

The purpose of this study was to investigate a method of reducing the loss of heat energy from the interior of the school welding laboratory when mechanical exhaust fans are used to evacuate electric arc and gas welding fumes to the atmosphere.

Objectives of the Study

The objectives of the study were as follows:

1. To develop a mechanical air charging system which would complement the cross-flow welding fumes exhaust system utilized in the Agricultural Mechanics Laboratory, Campus Farm, The University of Arizona.

2. To evaluate the effect of an air charging system upon reducing laboratory heat energy loss when the existing cross-flow welding fumes exhaust machinery is operated.

3. To evaluate the operating efficiency of the existing cross-flow welding fumes exhaust system when modified to incorporate a mechanical air charge system utilizing atmospheric air.

Physical Facilities and Hardware Used in the Study

The physical shape and arrangement of the Agricultural Mechanics Laboratory, Campus Farm, The University of Arizona is similar to the facilities in which instruction in agricultural mechanics is conducted in Arizona high schools offering vocational agriculture. The masonry structure is rectangular-shaped with an interior dimension of 34 ft. wide and 78 ft. long. The ceiling is acoustical tile with a clearance of 11 ft. The total volume of the laboratory is approximately 29,000 ft^3. There are two personnel doors and one 10' x 11' overhead door. The east end of the facility houses eight electric arc welding and eight gas welding stations. The arc welding stations are portable to the extent that any or all can be removed from the area to provide additional floor area if needed. The gas welding stations are permanently secured to the concrete floor. Each of the arc and gas welding stations are provided with a cross-flow welding fumes exhaust system that moves the fumes away from the welder and mechanically exhausts them to the outside atmosphere. The system is powered by two 3/4 hp electric motors driving fans which have a total rated displacement capacity of 4,000 ft^3 per minute. Thus, an airflow volume of 333 ft^3 is available at each of the 12 ducts. The fume pick-up boot for each arc welding station has a 12 inch diameter face opening attached to the arc screen. The boot is located at the back edge of the welding table and directly away from the student welder. The funnel-shaped boot narrows to accept a 4 inch exhaust duct with an area of .087 ft^2. The velocity of air in the duct was calculated at approximately 3,400 lineal feet per minute. Airflow measurements taken with an Alnor 6000 AP Velometer at the point of fume generation during flat position welding (approximately 12 inches from the face of the intake boot) were within the OSHA standards for a capture velocity of 100 lineal feet per minute, 4 to 8 inches off the surface of the table.

Two large 1 hp evaporative coolers are mounted in the west wall of the laboratory. During the late spring, summer and early fall the coolers are operated to provide a comfortable instructional environment. During the winter months two overhead gas fired space heaters provide

adequate heat for the laboratory assuming the doors, windows and louvers on the evaporative coolers are closed. However, when the welding fumes exhaust system is operated, the heated interior laboratory air is being exhausted at the rate of 4,000 ft^3/minute. Adequate outside make-up air enters the louver openings of the evaporative coolers. The heat air loss is approximately 14 percent of the total air volume of the laboratory per minute when the exhaust system is in operation. At this rate, assuming an air temperature difference of 30°F, the heat energy loss would be 137,140 BTU's per hour.[1] To maintain a room temperature of 70°F, the heating system would require approximately 1.5 gallons of propane[2] or 137 ft^3 of natural gas[3] fuel per hour. At the air temperature difference used in this example, the cost of heating the incoming air would approach $1.50 per hour or $9.00 per day when the schedule consists of two classes each requiring three hours of laboratory time. Reducing the heat loss one-half by introducing outside air directly into the exhaust airstream would provide an energy saving of nearly $360.00 per semester when the laboratory is scheduled for six hours per day, five days per week.

METHODS OF PROCEDURE

Several methods were contemplated as a means of charging outside air into the existing cross flow exhaust system. The charge system evaluated and reported in this study was believed to be the best alternative to complement the design of the welding station hardware used in the laboratory.

Design of the Air Charge System

The design of the charging system consisted of sheetmetal air diffusers mounted on three sides of the free standing welding table, Figure 1. The

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[1] Calculation for heat energy loss in BTU's/hr:

$$\text{BTU's/hr} = \frac{\text{Ft}^3\text{/min x 60 min/hr x Degree F Temp. Diff. x .24 BTU's/lb/deg F}}{\text{Air, Ft}^3\text{/lb.}}$$

$$137{,}142 \text{ BTU/hr} = \frac{4{,}000 \text{ ft}^3\text{/min x 60 min/hr x 30°F x .24 BTU's/lb/deg F}}{12.6 \text{ ft}^3\text{/lb}}$$

[2] Propane - 93,000 BTU/gal

[3] Natural gas - 1000 BTU/ft^3

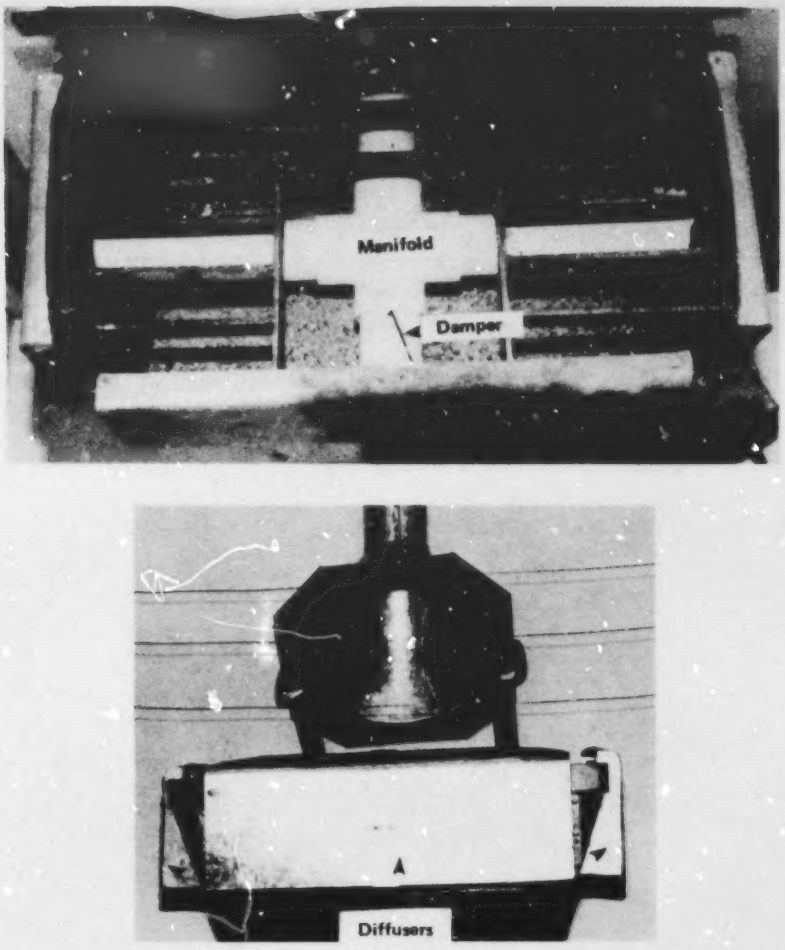

FIGURE 1. Air charge system attached to welding table with manifolds (Top View) and sheetmetal diffusers on three sides. Exhaust intake boot at back.

diffusers were supplied with air from a manifold consisting of 2 inch diameter Schedule 30 PVC plastic pipe. Dampers were placed in each of the three manifold pipes to control the discharge from each air diffuser. Air to the manifold was conveyed by flexible conduit from the discharge of a Dayton fan having a capacity of 530 ft^3/min. A nine position control valve was installed in the discharge of the fan to meter the amount of air entering the diffusers.

Calibrating the Air Charge System

To calibrate the system, a box measuring 8 ft. in length, 4 ft. wide and 8 ft. high was constructed and placed immediately under the intake duct of one arc welding station, Figure 2. The welding table equipped with the air charge diffuser and manifold was placed in the box in order that the cross-flow intake boot and exhaust pipe could be attached to the common exhaust fan duct. With the table in place at one end of the box, all seams and openings in the sheetrock siding were sealed with masking tape.

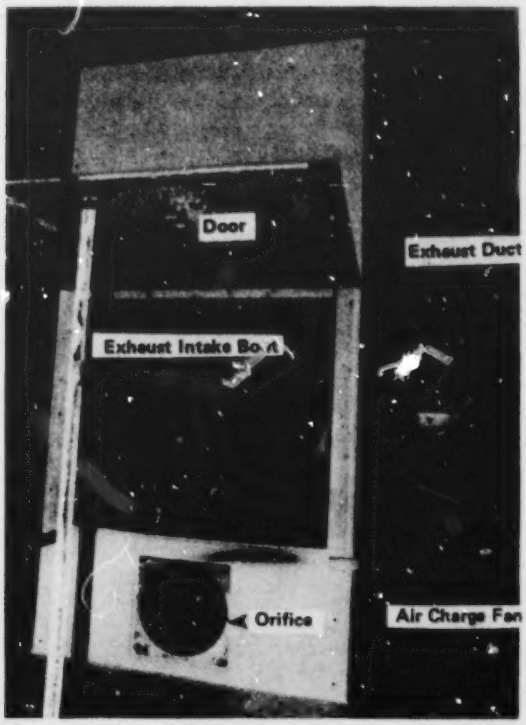

FIGURE 2. Air box with calibrating orifice, welding station and air charge fan.

A 28 ga. sheetmetal calibration orifice was installed in the sheetrock at the opposite end of the box. The diameter of the orifice was 13.54 inches which provided an area of one ft^2. The orifice was divided into nine quadrants by placing 30 ga. wire on 4 inch centers. This was done to measure the airflow through the orifice with a velometer and arrive at a mean airflow volume in ft^3/min. A personnel entrance door was placed in the end of the box immediately above the calibration orifice. The door sealed against a gasket when closed. The Dayton charging fan was placed outside the box and connected to the charging manifold of the welding table by flexible conduit.

The airflow from one of the six welding stations was connected to the cross-flow intake boot inside the calibrating box. No change was made in the exhaust system of the remaining five stations. Since the six stations were serviced by one of the two 2,000 ft^3/min exhaust fans it was calculated that the quantity of airflow through the calibrating orifice without the charging fan operating would be approximately 333 ft^3/min ($\frac{2000\ ft^3/min}{6\ station}$). An Alnor 6000 AP Velometer equipped with 0-1250 lineal ft. per minute range selector and diffuser probe was used to measure the airflow at each of the nine quadrants in the calibrating orifice. Each quadrant was evaluated six times and a mean airflow volume calculated as reported in Table 1. The maximum airflow of 318.33 ft^3/min (line 1, Table 1) was 95.45 percent of the calculated volume to be exhausted at the station.

Table 1

Rate of Charge Air Introduced into Cross-flow Welding Exhaust System's Intake Boot in Cubic Feet/Minute and Percent Charging Air

Air Charge Motor Condition	Damper Position	Volume of Exhaust Air ft^3/Minute*	Volume of Air Charge ft^3/Minute**	Outside Charge Air, Percent
OFF	-	318.33	--	--
ON	1	300.00	18.33	5.80
ON	2	275.00	43.33	13.60
ON	3	255.00	63.33	19.90
ON	4	240.00	78.33	24.60
ON	5	225.00	93.33	29.30
ON	6	210.00	108.33	34.00
ON	7	200.00	118.33	37.20
ON	8	180.00	138.33	43.45
ON	9	165.00	153.33	48.20

*Measured at air box orifice.
**Calculated volume.

The series of nine tests reported in Table 1 required the operation of the Dayton charge fan and positioning the damper through each of nine positions to vary the volume of charge air entering the air diffusers at the welding table. The cross-flow exhaust fan was operated at the discharge rate of 318.33 ft /min. through each of the nine tests. For each damper position, readings were taker with the Alnor velometer at each of the nine quadrants in the air box orifice. The "Volume of Exhaust Air, ft^3" as listed in Table 1 are the mean values for six replications of readings for each damper setting.

It was determined that the maximum amount of outside air that could be introduced into the airflow pattern of the exhaust system with the Dayton fan and the air charging system was 48.2 percent of that exhausted from the air box.

EVALUATING THE AIR CHARGE SYSTEM

The air charge system was evaluated on its ability to conserve heat energy, to complement and enhance the efficiency of the cross-flow system, and to capture and exhaust welding fumes. The effectiveness of the system was evaluated as follows:

1. To calculate the effect of air charging on heat energy conservation.

2. To determine the effect of the air charge system on the capture velocity of the airflow at various positions on the welding table for each of the nine damper positions on the exhaust fan.

3. To determine the efficiency of the cross-flow exhaust system to evacuate welding fumes when air charge was provided.

Effects of Air Charge on Heat Energy Conservation

Based upon the results of the data presented in Table 1, the calculated amount of energy loss for seven levels of temperature differences to maintain 70°F room temperature is presented in Table 2. The calculations to arrive at the number of BTU/hour that were required as make-up heat are based upon the amount of space occupied by air in ft^3/lb. at various temperatures. These values are presented in Table 3.

From these data the values in BTU/hr. heat energy loss were computed for ten different percentages of air charge. For example, if the outside air temperature was 30 F less than the 70 F in the laboratory and no air charge was used, the heat energy loss would be 10,914 BTU's/hr. per welding station or a total of 130,968 BTU's/hr. for the 12 stations. Assuming 43.45 percent of air charge was used, the amount of heat loss would be 6,171 BTU's/hr. per station or 74,050 BTU's for 12 stations. The difference in total building heat loss from this example would amount to an energy saving of 56,916 BTU's per hour or .61 of a gallon of propane[1] or 56.9 ft^3 of natural gas[2] per hour of operation.

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[1]Propane - 93,000 BTU/gal

[2]Natural gas - 1000 BTU/ft^3

Table 2

Heat Energy Evacuated in BTU's/Hr. for Seven Temperature Differences to Maintain 70°F Room Temperature for Ten Rates of Air Charge in Percent Per Welding Station*

Outside Air Temp. Diff. to Room, Deg. F	Percent Outside Air Charge									
	0.0	5.8	13.6	19.9	24.6	29.3	34.0	37.2	43.45	48.2
10	3,499	3,298	3,023	2,813	2,638	2,473	2,308	2,198	1,979	1,814
20	7,146	6,734	6,173	5,724	5,387	5,051	4,714	4,489	3,367	3,704
30	10,914	10,286	9,428	8,743	8,228	7,714	7,200	6,857	6,171	5,657
40	14,786	13,935	12,774	11,845	11,148	10,452	9,755	9,290	8,361	7,669
50	18,958	17,866	16,377	15,186	14,293	13,399	12,506	11,911	10,720	9,826
60	23,229	21,892	20,068	18,608	17,514	16,419	15,324	14,595	13,135	12,040
70	27,686	26,091	23,917	22,178	20,873	19,569	18,264	17,394	15,655	14,350

*Heat energy loss in BTU's/hr. based on an exhaust rate of 318.33 ft^3/minute.

Table 3

Number of Cubic Feet Occupied by One Pound of Air for Eight Temperatures, Degrees F

Volume of Air - Cubic Feet Per Pound Temperature, Degrees F							
0°	10°	20°	30°	40°	50°	60°	70°
11.59	11.84	12.09	12.40	12.60	12.83	13.10	13.35

Effect of Air Charge Applied to Arizona

Application of these data to climatic conditions in Arizona is presented in Table 4. Mean temperatures were obtained for the nine month school year, September through May, according to school location based upon elevation. The table identifies the heat energy evacuated in BTU's/hr. for six percentages of air charge. For example, the geographic location of a school at the 5,000 ft. elevation can expect to have a mean temperature during the school year of 47.3°F. Assuming the school was operating 12 welding stations each discharging 318.33 ft^3 of air per minute, five hours per day would result in approximately 487 ft^3 of natural gas per day. With 43.45 percent air charge, the amount of natural gas required to maintain the laboratory at 70°F would be approximately 275 ft^3 per day. Based upon an effective 160 day school year, approximately 33,920 ft^3 of natural gas ($203.50 heating cost) could be saved by using the air charging system.

Table 4

Heat Energy Evacuated in BTU's/Hr* Per Welding Station for Mean Temperatures Occurring Between September-May, With School Location Based Upon Elevation to Maintain 70°F Room Temperature for Five Rates of Air Charge

Elevation, Feet	Mean Temp. °F	Percent Outside Air Charge					
		0	29.3	34.0	37.2	43.45	48.2
0	67.9	721	510	476	453	408	373
1,000	64.1	2065	1460	1363	1297	1168	1070
2,000	59.0	3849	2721	3903	3714	3344	3063
3,000	58.3	4094	2895	2702	2571	2315	2121
4,000	57.7	4304	3045	2841	2703	2434	2230
5,000	47.3	8110	5734	5353	5093	4586	4200
6,000	46.8	8308	5874	5483	5217	4698	4304
7,000	39.5	11096	7845	7323	6968	6275	5748
8,000	38.5	11460	8102	7564	7197	6481	5936

*Heat energy loss in BTU's/hr. based upon an exhaust rate of 318.33 ft^3/min.

Effects of Air Charge on Capture Air Velocity

The surface of the welding table was covered with a 1/4 inch x 24 inch x 16 inch steel plate marked off into 28 quadrants each 4 inches square, Figure 3. The quadrants were identified A-G on the 24 inch margin

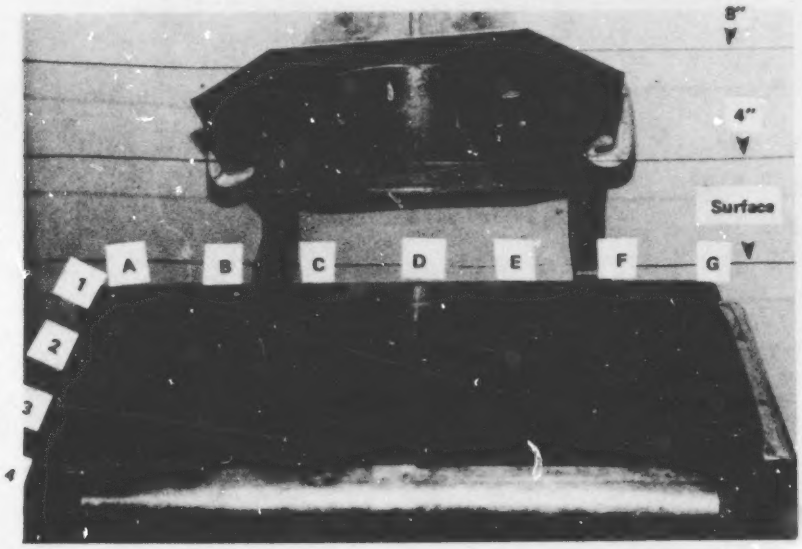

FIGURE 3. Surface of welding table marked off into 28 quadrants for measuring air velocity at three levels, surface, 4" and 8".

of the table and 1-4 on the 16 inch margin. Thus, the Alnor Velometer equipped with the LO-FLO Probe (0-300 ft/min) could be located to sample repeatedly the lineal airflow velocity in ft. per minute at the same points across the table. Sampling was conducted at the surface, 4 inches and 8 inches off the surface of the table. Samples were taken at each of the three levels for each of the nine settings of the damper of the charging fan. The data presented in Table 4 identify the readings in velocity obtained at the surface of the welding table in each of the 28 grid positions. Similarly, the data in Table 5 and 6 identify velocities 4 inches and 8 inches, respectfully, above the table.

The first line of the data presented in Tables 4, 5 and 6 is the velocity of the air moving toward the intake boot opening of the exhaust

Table 5

Capture Velocity of the Cross-flow Exhaust System in Feet Per Minutes Without and With Charge Air Supplied at Nine Different Volumes When Measured at Surface of Welding Table

Air Charge Fan Operation	Charge Air Input		Table Number Position	Capture Velocity of Air, Lineal Feet/Minute TABLE LETTER POSITION							Mean*
	CFM	Percent		A	B	C	D	E	F	G	
No	--	--	1	0	50	65	100	100	80	70	67.5
			2	<50	<50	80	80	90	85	70	
			3	<50	50	50	50	70	70	50	
			4	<50	50	60	60	60	50	<50	
Yes	18.33	5.8	1	<50	70	80	105	110	80	<50	73.0
			2	90	80	100	80	90	80	100	
			3	90	60	60	50	60	70	90	
			4	<50	110	110	105	100	100	0	
Yes	43.33	13.6	1	60	75	100	155	100	90	60	116.0
			2	240	140	160	100	130	100	250	
			3	250	160	100	0	130	140	250	
			4	<50	280	280	260	250	300	50	
Yes	63.33	19.9	1	50	70	120	180	120	100	50	142.0
			2	300	200	220	100	180	120	300	
			3	300	200	100	0	150	150	300	
			4	80	300	300	300	300	300	50	
Yes	78.33	24.6	1	<50	80	100	180	120	100	<50	168.0
			2	500	230	250	140	200	130	500	
			3	500	230	150	0	180	170	500	
			4	50	500	500	500	500	500	50	
Yes	93.33	29.3	1	50	80	150	200	150	100	60	169.0
			2	600	280	280	120	210	170	600	
			3	600	230	170	0	180	150	600	
			4	50	600	600	600	600	600	50	
Yes	108.33	34.0	1	50	100	120	170	180	130	60	211.0
			2	650	300	300	130	250	150	650	
			3	650	280	200	0	200	300	650	
			4	50	650	650	650	650	690	50	
Yes	118.33	37.2	1	60	100	160	200	200	150	70	223.0
			2	700	300	300	180	300	150	700	
			3	700	300	250	0	250	200	700	
			4	70	700	700	700	700	700	70	
Yes	138.33	43.45	1	50	70	190	200	200	130	90	225.0
			2	750	300	300	180	300	200	750	
			3	750	250	220	0	250	250	750	
			4	70	750	750	750	750	750	70	
Yes	153.33	48.2	1	50	60	300+	300+	300+	120	80	223.0
			2	800	300+	300+	180	300+	250	800	
			3	800	300+	150	0	200	250	800	
			4	70	800	800	800	800	800	70	

*Effective Mean Velocity = Area positions of 2B - 2F and 3B - 3F only.
Note: Velocities over 300 measured with 0-1250 Range Selector.

Table 6

Capture Velocity of the Cross-flow Exhaust System Without and With Charge Air Supplied at Nine Different Volumes When Measured 4 Inches Above Surface of Welding Table

Air Charge Fan Operation	Charge Air Input		Table Number Position	Capture Velocity of Air, Lineal Feet/Minute TABLE LETTER POSITION							Mean*
	CFM	Percent		A	B	C	D	E	F	G	
No	--	--	1	<50	100	140	150	180	120	50	91.0
			2	<50	60	110	140	130	100	50	
			3	<50	60	80	90	80	60	50	
			4	<50	< 50	60	60	50	50	<50	
Yes	18.33	5.8	1	50	105	180	180	200	150	<50	90.5
			2	<50	60	135	150	130	90	< 50	
			3	<50	50	70	80	80	60	< 50	
			4	<50	< 50	50	50	50	< 50	< 50	
Yes	43.33	13.6	1	<50	80	150	180	200	100	50	101.0
			2	< 50	60	160	150	160	70	< 50	
			3	<50	50	80	80	150	50	< 50	
			4	<50	< 50	< 50	50	50	< 50	< 50	
Yes	63.33	19.9	1	<50	60	130	200	200	100	50	110.0
			2	<50	60	200	150	200	80	50	
			3	<50	< 50	80	80	150	50	< 50	
			4	<50	< 50	50	50	50	< 50	< 50	
Yes	78.33	24.6	1	<50	80	130	250	190	120	50	152.0
			2	<50	60	230	150	230	70	<50	
			3	<50	170	110	150	250	100	< 50	
			4	<50	< 50	50	50	50	50	<50	
Yes	93.33	29.3	1	<50	60	130	210	170	70	50	161.0
			2	<50	60	250	170	230	80	50	
			3	<50	200	150	100	270	100	<50	
			4	<50	< 50	50	50	50	50	50	
Yes	108.33	34.0	1	50	60	130	240	230	100	50	184.0
			2	<50	70	290	200	290	100	70	
			3	70	230	150	120	290	100	70	
			4	70	70	80	80	80	80	70	
Yes	118.33	37.2	1	<50	60	130	260	180	100	70	188.0
			2	70	90	300+	180	300	100	80	
			3	70	220	150	120	300+	120	80	
			4	70	70	80	80	80	70	70	
Yes	138.33	43.45	1	<50	60	150	290	210	130	120	213.0
			2	60	90	300+	190	300+	100	70	
			3	70	300+	200	150	300+	200	70	
			4	70	70	80	80	80	70	70	
Yes	153.33	48.2	1	<50	60	200	250	200	80	<50	206.0
			2	70	120	300+	220	300+	120	70	
			3	70	200	150	140	300+	210	70	
			4	70	80	80	80	80	80	70	

*Effective Mean Velocity = Area positions of 2B - 2F and 3B - 3F only.

Table 7

Capture Velocity of the Cross-flow Exhaust System Without and With Charge Air Supplied at Nine Different Volumes When Measured 8 Inches Above Surface of Welding Table

Air Charge Fan Operation	Charge Air Input		Table Number Position	Capture Velocity of Air, Lineal Feet/Minute TABLE LETTER POSITION							Mean*
	CFM	Percent		A	B	C	D	E	F	G	
No	--	--	1	<50	60	210	290	290	150	<50	133.5
			2	<50	80	120	300	280	80	<50	
			3	<50	50	110	155	100	60	<50	
			4	<50	<50	50	50	50	50	<50	
Yes	18.33	5.8	1	<50	60	250	300+	300+	<50	<50	147.0
			2	<50	80	230	300+	300+	70	<50	
			3	<50	50	110	150	120	60	<50	
			4	<50	<50	50	50	50	50	<50	
Yes	43.33	13.6	1	<50	<50	300+	300+	300+	<50	<50	139.0
			2	50	60	200	290	290	70	<50	
			3	<50	60	110	130	120	60	<50	
			4	<50	<50	<50	<50	<50	<50	<50	
Yes	63.33	19.9	1	<50	<50	150	300+	300+	<50	<50	132.0
			2	<50	60	210	280	250	70	<50	
			3	<50	<50	100	120	120	60	<50	
			4	<50	<50	50	50	50	50	<50	
Yes	78.33	24.6	1	<50	<50	250	300+	170	80	50	141.0
			2	<50	90	200	270	270	80	<50	
			3	<50	60	100	130	140	70	<50	
			4	<50	<50	50	50	<50	<50	<50	
Yes	93.33	29.3	1	<50	<50	300+	300+	300+	110	<50	170.0
			2	<50	80	300+	300+	300+	100	50	
			3	60	100	120	150	150	100	60	
			4	<50	50	60	60	60	50	<50	
Yes	108.33	34.0	1	<50	<50	300+	300+	300+	80	70	170.0
			2	60	80	300+	300+	300+	80	70	
			3	70	100	140	150	150	100	80	
			4	60	80	80	80	80	70	70	
Yes	118.33	37.2	1	50	<50	300+	300+	300+	120	60	184.0
			2	60	80	300+	300+	300+	70	70	
			3	70	100	150	130	270	120	80	
			4	70	70	70	70	70	70	70	
Yes	138.33	43.45	1	<50	<50	300+	300+	300+	70	<50	180.0
			2	50	60	300+	300+	300+	70	70	
			3	50	120	200	120	250	80	70	
			4	70	70	70	70	70	70	70	
Yes	153.33	48.2	1	<50	<50	300+	300+	300+	<50	<50	114.0
			2	70	70	200	250	120	70	70	
			3	60	80	100	100	80	70	70	
			4	70	70	70	70	70	70	70	

*Effective Mean Velocity = Area positions of 2B - 2F and 3B - 3F only.

system without the charge fan in operation. These data are provided to compare the influence of air charge on the capture velocity at each of the nine damper settings. The effective capture velocity was considered to be in the areas of the table where the student would do most of the welding. This was determined to be in the ten grid area sections 2B-2F and 3B-3F. The mean velocity reported in Tables 4, 5 and 6 were calculated for these ten grid areas. These values are hereafter referred to as the effective mean velocities.

As indicated in Table 4, there is a definite increase in the velocity of the air across the table as the amount of charge air is increased. As would be expected, the velocity at each of the diffuser openings, positions A 1-4, G 1-4 and 4 B-F was especially high. At other positions except for D-3 the velocities steadily increased to well over the 100 lineal ft/min. recommended by OSHA. At D-3 the readings taken were all 0 ft/min. velocity. Apparently, the airflow at this position was not in the direction of the exhaust boot. This characteristic was not found in position D-3 at 4 and 8 inches above the welding table.

The effective mean velocities reported in Tables 4 and 5 support the hypothesis that adding charge air to the perimeter of the table would complement the cross-flow exhaust system by increasing the lineal flow of air at the welding station. At the surface, Table 4, the mean velocity was calculated at 67.5 ft/min. with only cross-flow exhaust operating. The maximum mean velocity of 225 ft/min. was measured when 43.45 percent air charge was added to the system. The increase in airflow at the surface of the table as a result of the air charge was approximately 230 percent.

When the mean air velocities are evaluated at 4 inches above the surface of the table, the range was 91 ft/min. with exhaust air only and 213 ft/min. with 43.45 percent air charge. The increase was approximately 134 percent due to air charge.

Similarly, the mean velocity of airflow 8 inches above the table was 133.5 ft/min. when only cross-flow exhaust was used (Table 6). When air charge was employed, a maximum mean velocity of 184 ft/min. was obtained at a charge rate of 37.2 percent. The velocity increase by the addition of air charge was approximately 39 percent.

Effects of Air Charge on the Evacuation of Welding Fumes

During the time that the welding table and exhaust system were located in the air box, actual welding was performed in an attempt to observe smoke flow patterns and efficiency of the exhaust system. The air charge system was operated through each of the nine damper positions as a technician welded with an E6011 electrode using 100 amperes welding current. The author remained outside the box and attempted to observe the smoke flow patterns through an inspection plate guarded for direct exposure to the arc rays.

The visual observation suggested that the welding smoke generated was evacuated even when the air charging system was operated at the number six damper position which gave 34.0 percent air charge. It is noted from Figure 4, left-hand column, fumes apparently were being "pushed" by the charge air under the intake boot of the cross-flow system at the 48.2 percent rate. The right-hand column of pictures were taken after a deflection shield was installed. A 20 ga. sheet of steel was bent to a 45° angle and attached to the rear of the welding table. It was assumed the deflector would direct the air charge into the exhaust intake. The deflector appeared to solve the problem as indicated in the comparison photos of maximum charge air (48.2%), Figure 4. However, it was difficult to detect whether any fumes were still escaping into other parts of the box. It was also believed that the confines of the air box were influencing the effectiveness of the system. Therefore, the air box was disassembled and the welding table containing the air charge diffuser and manifold and the exhaust boot were repositioned in its normal operating format as a complete student welding station.

The Risk Management Division of the University was contacted for technical assistance. Mr. Steve Holland, Industrial Hygienist with the Division, outlined a method of using standard industrial procedures for sampling the smoke and fume emissions and arranged for the Analytical Center, The University of Arizona, to perform a chemical analysis of the fume samples for iron oxide content. Iron oxide fumes are the most prevalent chemical present when welding steel.

The sampling equipment included two portable Personal Sampling Vacuum Pumps (a Mine Safety Appliance Pump Model S and a DuPont High Flow Pump Model P2500a). Each pump was calibrated using the standard soap bubble Universal Pump Calibrator and adjusted for flow rate of 1.4 liters per minute. A plastic cassette containing a mixed cellulose ester filter was connected by Tygon hose to the pump. One cassette was attached to the welding helmet at the breathing zone and the pump clipped to the belt of the welder. The second pump was equipped with the same type filter cassette and positioned in the welding station equipped with the air charge system. The pump was placed approximately four feet off the floor and in close proximity to the welding table. Its purpose was to sample for fumes not entering the cross-flow intake boot of the exhaust system and contaminating the area.

Testing for fumes was conducted in cooperation with one of the scheduled Agricultural Mechanics classes, during the time college students were using the arc welding equipment. Six students were involved in conducting the tests. One of the students was fitted with the portable pump. The filter cassette was positioned in the helmet to sample fumes entering the student's breathing zone. The filter was connected to the pump by plastic tubing. All students were directed to build up a low carbon steel plate by padding, using E6011 welding electrodes and the A/C welding machine set to 100 amperes welding current. The following three tests were conducted:

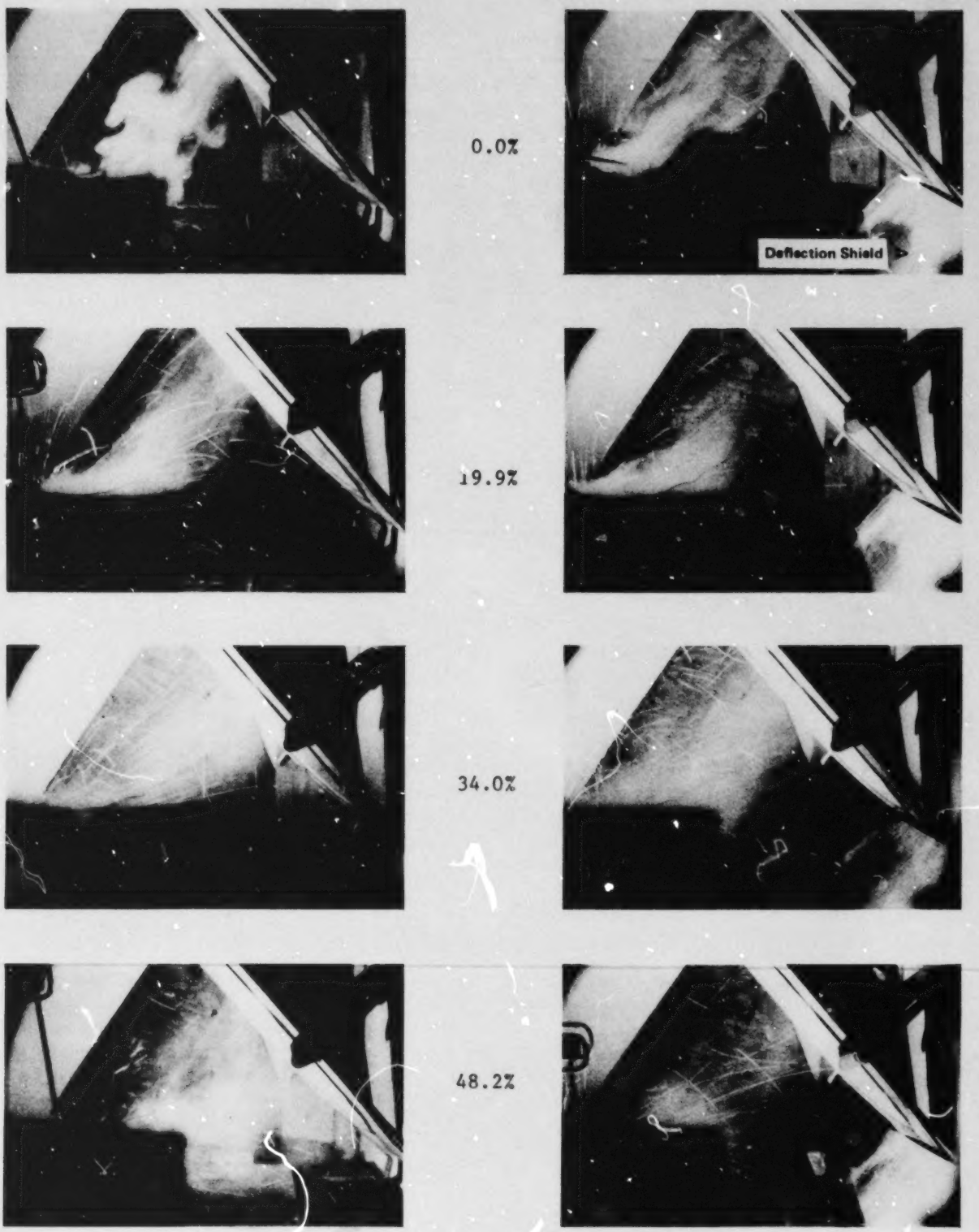

FIGURE 4. Comparison of smoke action generated by E6011 electrode and the influence of air charge by volume for four percentage rates of cross-flow exhaust. Left column is without deflection shield.

1. Air samples in the area and helmet with all doors and windows closed and no mechanical exhaust or air charge in use.

2. Air sample in the area and helmet when the cross-flow exhaust system was operated.

3. Air samples in the area and helmet when the cross-flow exhaust and air charge system were operated. The damper of the charging fan was set in number nine (maximum) position which provided a volume of 153.33 ft^3/min. flow of air from the diffusers at the welding table.

The operational procedure for conducting the first test was to close all doors and windows, to turn off the evaporative coolers and the six students instructed to weld until a visible atmosphere of welding fumes developed in the laboratory. At this time, the two vacuum pumps were started and the students continued to weld for a period of 27 minutes. The data presented in Table 8 identify that the volume of iron oxide collected on the area sample filter was 2.74 mg/m^3 and 2.27 mg/m^3 on the helmet filter.

Table 8

Analysis of Iron Oxide Contained On
Air Filter Samples From Area and
Helmet Collection Points

Test No.	Method of Exhaust	Filter Location	Volume of Air Sampled			Results of Analysis	
			Rate ℓ/min	Time min	Volume ℓ/filter	μg/filter	mg/m^3*
1	None	Area	2.00	27	54.00	148.0	2.74
		Helmet	1.46	27	39.42	89.5	2.27
2	Cross-flow Exhaust	Area	2.00	27	54.00	14.9	.275
		Helmet	1.46	27	39.42	11.8	.299
3	Cross-flow plus Air Charge	Area	1.54	27	41.58	15.9	.382
		Helmet	1.46	27	39.42	9.1	.230

*Calculation:

$$mg/m^3 = \frac{\mu g/filter}{vol\ \ell/filter} \times \frac{1\ mg}{1{,}000\ \mu g} \times \frac{1{,}000\ \ell}{1m^3}$$

For test No. 2, the area was evacuated of all welding fumes by opening the windows and doors. When the laboratory was visibly clear of fumes, the windows and doors were closed, the cross-flow ventilation system was turned on and the students instructed to continue welding on the same build-up padding sample with the E6011 electrode. For test No. 2, both vacuum pumps were operated for 27 minutes and the filters evaluated. For this test (No. 2), .275 mg/m^3 of iron oxide was collected on the area filter and .299 mg/m^3 on the helmet filter.

Test No. 3 included the processes and procedure used in Test No. 2 plus the operation of the charge fan. After 27 minutes of sampling time, the two filters were evaluated and found to have collected .382 mg/m^3 and .230 mg/m^3 of iron oxide from the area and the helmet, respectively.

The data of 2.74 and 2.27 mg/m^3 iron oxide for area and helmet, respectively, indicates that the helmet does offer a deterrent to the amount of fumes breathed by the operator. In this instance there was 17% less iron oxide collected in the helmet. The Threshold Limit Values (TLV) established by the American Conference of Governmental Industrial Hygienists (ACGIH) is 5 mg/m^3 inside the welding helmet.[1] When no ventilation was used, the 2.27 mg/m^3 collected on the filter was only 45.4% of the TLV limits for iron oxide.

For this study, the more important data presented in Table 8 was the influence of the air charge system upon the performance of the cross-flow exhaust system. In Test No. 2, it is noted that the amount of iron oxide collected on the filter was .299 mg/m^3 or 86.8 percent less than that obtained in Test No. 1.

In Test No. 3, an air charge volume of 48.2 percent of the exhaust rate was added to the table. For this test, the amount of iron oxide collected in the helmet was .230 mg/m^3. This was approximately 23.1 percent less than that which was measured in Test No. 2, (cross-flow exhaust only), and 89.7 percent less than when no ventilation was used. It is noted, however, that the amount of iron oxide collected in the welding area in Test No. 3 was .382 mg/m^3 or a 38.9 percent increase over the .275 mg/m^3 collected for the area in Test No. 2. Apparently, the air charge system was effective in reducing the fumes that would normally occur in the breathing zone compared to that experienced when only the exhaust system was operating. However, the increase of area contamination (although 86.8 percent less than when no exhaust was used) suggests that the amount of air charge was too great and that additional air charge rates should be evaluated.

FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

The findings, conclusions and recommendations are based upon the data collected in this study. Due to limited time and resources, only one method of incorporating air charge in welding exhaust ventilation was investigated.

Findings

Analysis of the data developed in investigating the effectiveness of an air charge system to complement an existing cross-flow welding fume exhaust system provided the following findings:

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[1] Based on true weighed averages (TWA) of 8 hours.

1. Considering the limitations on the design of the air charge manifold, the air diffusers and the discharge volume of the charging fan, heat loss from the welding laboratory was reduced approximately 48 percent by the introduction of outside air into the intake duct of the evacuation system.

2. The air charge system developed for this study complemented the cross-flow exhaust system by increasing the capture velocity of airflow toward the intake boot of the system at the surface of the welding table. The velocity increased from a mean of 67.5 feet per minute when no air charge was used to a mean of 223 feet per minute when a maximum air charge of 43.45 percent was utilized. This resulted in an increase of 230 percent in velocity of the air. When measured 4 inches above the surface of the welding table, the increase was from a mean of 91 lineal feet/minute to 213 feet per minute or an increase of 134 percent in airflow. At the 8 inch height, the maximum mean velocity of airflow was 184 feet per minute at 37.2 percent air charge.

3. The 2.74 mg/m^3 of iron oxide collected in the breathing zone on the cassette sampling filter during the 27 minutes that no mechanical ventilation was used was approximately 55 percent of the 5.00 mg/m^3 TVL limits established by ACGIH.

4. The operation of the cross-flow exhaust system reduced the amount of iron oxide collected in the breathing zone of the welding helmet during the 27 minutes the samples were taken by 89.9 percent compared to when no ventilation was used.

5. When the air charge system was operated at the 48.2 percent rate, the amount of iron oxide collected in the breathing zone was reduced 23 percent compared to the amount when only the cross-flow exhaust system was used. However, the amount of iron oxide collected in the area increased by approximately 39 percent when both air charge and cross-flow exhaust systems were operating.

Conclusions

Based upon the analysis of data and findings, the following conclusions were formulated for this study:

1. When properly designed, the amount of outside unheated air which may be introduced into the cross-flow welding exhaust system by air charge could reduce costs of heating make-up air by 48 percent or more.

2. An air charge of the design used in this study complements the cross-flow welding exhaust system by increasing the capture velocity of the exhaust boot, especially at the surface and 4 inches above the surface of the welding table.

3. When maximum air charge was utilized in this study, the amount of iron oxide breathed by the student welder was reduced by 23 percent compared to when welding fumes were exhausted only by the cross-flow ventilation system. The amount of area fumes increased by 34 percent which suggested that some iron oxide welding fumes were blown away from the student welder and entered the area of the welding station rather than being picked up by the exhaust boot of the cross-flow welding fume exhaust system. However, the level of contamination was still 92 percent less than the TLV level of 5 mg/m^3 established by OSHA/ACGIH.

4. The Threshold Limit Values of breathing zone exposures to iron oxide fumes of 5 mg/m^3 as established by OSHA/ACGIH may not be exceeded by even the most primitive ventilation system.

Recommendations

From the findings reported herein, it is recommended that additional studies be conducted to:

1. Develop the most appropriate design and procedure to produce an efficient air charge for the cross-flow welding fumes exhaust system.

2. Investigate the concept of adding air charge to exhaust systems other than the cross-flow type and to evaluate the performance.

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